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Application of the Finite-Element MICHELLE Beam Optics Code to RF Gun Modeling

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Abstract: *RF guns and density modulated guns that encompass photocathodes and inductive output tube sources are difficult to model but continue to be at the forefront of solutions to many applications. Modeling these density-modulated beam sources requires a high degree of computational mesh resolution to resolve geometrical features, or simply fine spatial scale phenomena. This paper presents the application of the MICHELLE code to such devices.*

Keywords: Beam formation; beam optics; charge exchange; computer-aided design (CAD); electron gun; ion plasma; ion thrusters; MICHELLE; multistage depressed collector; multibeam gun; object-oriented design; Voyager.

Introduction

The new MICHELLE [1], [2] two-dimensional (2D) and three-dimensional (3D) steady-state and time-domain particle-in-cell (PIC) code has been employed successfully by industry, national laboratories, and academia and has been used to design and analyze a wide variety of devices, including multistage depressed collectors, gridded guns, multibeam guns, annular-beam guns, sheet-beam guns, beam-transport sections, and ion thrusters. In this presentation we will investigate the application of the Electrostatic time-domain model to density modulated RF guns such as IOTs and photocathodes

Background

Modeling of density modulated RF guns involves modeling beam bunches in at least a portion of the domain that includes an RF cavity. To do this, two code models are needed; an EM frequency-domain code and a PIC code. In this work, we use the STAR ANALYST [3] code for the Frequency Domain solutions and the NRL/SAIC MICHELLE code for the PIC solutions. The RF fields from ANALYST are imported into the MICHELLE code and clocked in time. MICHELLE adds the self fields and emits the beam according to some emission rule, photoemission or thermionic, for the cases of interest.

Applications

For photocathodes, modeling includes superimposing an RF fields onto the self fields of the beam, and an adequate photoemission model must be included. We employed the NRL photoemission model [4] in the MICHELLE code, and can capture detailed effects of the emission surface and beam evolution.

For an IOT gun, the RF portion of the cavity is limited to the region from the emitter to the grid for beam modulation, with the main acceleration from the grid to anode DC fields. A DC bias voltage on the grid controls pulse length. In this case, an adequate thermionic emission model [1] that can capture the effects of the low field region with geometric complexity of the fields is important.

Figure 1 illustrates a typical IOT gun geometry. In IOTs, the cavity supports the density modulating fields between the emitter and the grid. The grid geometries are very complicated, and proprietary, as they act as an RF cavity wall and try to have high beam transmission. Figure 2(a) shows an example MICHELLE application to a non-intercepting gridded gin. We desire to capture the effect of the grid on the beam that is generated. Highly disparate spatial scales exist which demands a fine mesh in regions and is challenging to the code.

Additionally, as illustrated in Figure 2(b), the region between the emitter and grid during portions of the RF cycle has very low fields and complicated geometry, both which stress the ability of the emission algorithm to accurately predict beam current.

We will report on our progress in these areas.

References

1. John Petillo, et al., "The MICHELLE Three-Dimensional Electron and Collector Modeling Tool: Theory and Design", IEEE Trans. Plasma Sci., vol. 30, no. 3, June 2002, pp. 1238-1264.
2. John Petillo, et al., "Recent Developments in the MICHELLE 2D/3D Electron Gun and Collector Modeling Code", IEEE Trans. Electron Devices Sci., vol. 52, no. 5, May 2005, pp. 742-748.
3. Analyst is a commercial finite-element package for electromagnetic design. www.staarinc.com.
4. K. Jensen, et al., "The Quantum Efficiency of Dispenser Photocathode: Comparison of Theory to Experiment" Applied Physics Lett. 85, 22, 5448, 2004.

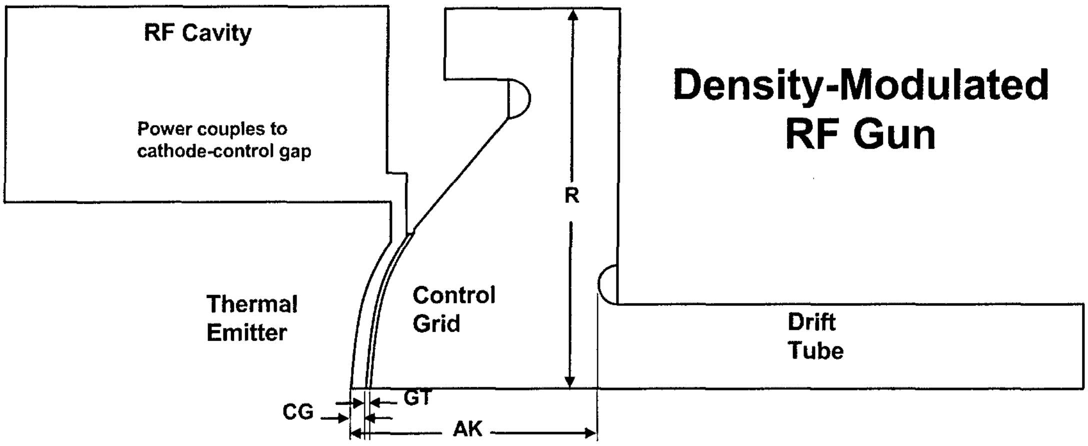


Figure 1: This figure illustrates an example of a high order mode inductive output tube (HOM-IOT). In IOT, it is often the case that disparate spatial scales exist in the region of the grid and the emitter to grid gap.

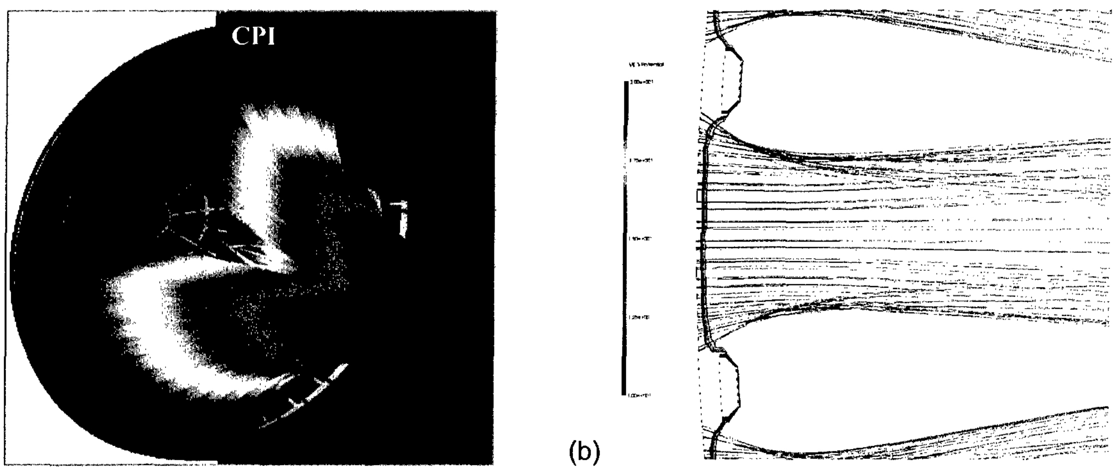
(a) 

Figure 2. The geometry of a CPI gridded gun with the MICHELLE predicted particle orbits colored by energy are shown in (a). Shown in (b) is a detailed view of particle trajectories in a plane with superimposed potentials ranging from 10–20 V. Cases such as these have complicated field structures in the vicinity of the emitter and improved models must account for the low voltages.